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TITLE: LIGHT EMITTING DIODE DRIVER

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LIGHT EMITTING DIODE DRIVER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to light emitting diode ("LED") arrays. The present invention specifically relates to a LED array powered by an alternating current supplied by a high frequency inverter circuit, and LED arrays controlled by impedance array that may be switching to accomplish dimming and switching functions.

2. Description of the Related Art

LEDs are semiconductor devices that produce light when a current is supplied to them. LEDs are intrinsically DC devices that only pass current in one polarity and historically have been driven by DC voltage sources using resistors to limit current through them. Some controllers operate devices in a current control mode that is compact, more efficient than the resistor control mode, and offers "linear" light output control via pulse width modulation. However, this approach only operates one array at a time and can be complex.

LEDs can be operated from an AC source if they are connected in an "anti-parallel" configuration as shown by patents WO98/02020 and JP11/330561. Such operation allows for a simple method of controlling LED arrays but which operate from a low frequency AC line. However, this approach employs large components and no provision is given for controlling the light output.

The present invention addresses the problems with the prior art.

SUMMARY OF THE INVENTION

The present invention is a light emitting diode driver. Various aspects of the present invention are novel, non-obvious, and provide various advantages. While the actual nature of the present invention covered herein can only be determined with reference to the claims appended hereto, certain features, which are characteristic of the embodiments disclosed herein, are described briefly as follows.

One form of the invention is a LED driver comprising a LED array, an inverter, and an impedance circuit. The LED array has an anti-parallel configuration. The inverter is operable to provide an alternating voltage at a switching frequency. The impedance circuit is operable to direct a flow of an alternating current through said LED array in response to the alternating voltage. In one aspect, the impedance circuit includes a capacitor and the LED array includes an anti-parallel LED pair, an anti-parallel LED string and/or anti-parallel LED matrix coupled in series to the capacitor. In another aspect, a transistor is coupled in parallel to the LED array with the transistor being operable to control (e.g., varying or diverting) the flow of the alternating current through the LED array.

The foregoing form as well as other forms, features and advantages of the present invention will become further apparent from the following detailed description of the presently preferred embodiments, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the present invention rather than limiting, the scope of the present invention being defined by the appended claims and equivalents thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a block diagram of a LED driver in accordance with the present invention;

FIG. 2 illustrates a first embodiment of the LED driver of FIG. 1 in operation with a first embodiment of a LED array in accordance with the present invention;

FIG. 3 illustrates the LED driver of FIG. 1 in operation with a second embodiment of a LED array in accordance with the present invention;

FIG. 4 illustrates a second embodiment of the LED driver of FIG. 1 in operation with a third embodiment of a LED array in accordance with the present invention;

FIG. 5 illustrates the second embodiment of the LED driver of FIG. 1 in operation with a fourth embodiment of a LED array in accordance with the present invention;

FIG. 6 illustrates a third embodiment of the LED driver of FIG. 1 in operation with a fifth embodiment of a LED array in accordance with the present invention;

FIG. 7 illustrates a first embodiment of an illumination system in accordance with the present invention; and

FIG. 8 illustrates a second embodiment of an illumination system in accordance with the present invention.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

FIG. 1 illustrates a LED driver 10 in accordance with the present invention for driving a LED array 40. LED driver 10 comprises a high frequency ("HF") inverter 20, and an impedance circuit 30. In response to a direct current I_{DC} from a direct voltage source V_{DC}, HF inverter 20 communicates an alternating voltage

V_{AC} to impedance circuit 30 at a switching frequency (e.g., 20 kHz to 100 kHz), which in turn communicates an alternating current I_{AC} to LED array 40. HF inverter 20 allows a compact and efficient method to control the current to LED array 40. At high frequencies, the current limiting components become compact in size. HF inverter 20 also allows for an efficient current control from direct voltage source V_{DC}. Forms of HR

inverter 20 include, but are not limited to, a voltage fed half bridge, a current fed half bridge, and a current fed push pull. Techniques known in the art can be employed to use frequency modulation to control output current which can be implemented to further improve the regulation of the proposed invention.

FIG. 2 illustrates a first embodiment of LED driver 10 (FIG.1) in accordance with the present invention. A HF inverter 20a includes a half-bridge controller 21 for controlling a half-bridge consisting of a transistor T_1 and a transistor T_2 in the form of MOSFETs. HF inverter 20a conventionally activates and deactivates transistor T_1 and transistor T_2 in an alternating inverse manner to produce a DC pulsed voltage (not shown) between transistor T_1 and transistor T_2. The DC pulsed voltage is dropped across a capacitor C_1 to produce a voltage square wave (not shown) to an impedance circuit 30a.

An impedance circuit 30a includes an inductor L_1 and a capacitor C_2 coupled to capacitor C_1 in series. Inductor L_1 and capacitor C_2 direct a flow of alternating current I_{AC} through a LED array 40a having a light emitting diode LED_1 and a light emitting diode LED_2 coupled in anti-parallel (i.e., opposite polarizations). Alternating current I_{AC} flows through light emitting diode LED_1 when alternating current I_{AC} is in a positive polarity. Alternating current I_{AC} flows through light emitting diode LED_2 when alternating current I_{AC} is in a negative polarity. Impedance elements L_1 and C_2 are connected with light emitting diode LED_1 and light emitting diode LED_2 in a "series resonant, series loaded" configuration. In this configuration, circulating current can be minimized and "zero voltage switching" of transistor T_1 and transistor T_2 can be realized resulting in an efficient and compact circuit.

A further benefit of this configuration is the ability to vary the current through the LEDs by varying the frequency of the half bridge. In such a configuration as frequency increases, current through the LEDs will generally decrease and as frequency decreases, current will increase. If a frequency control is added to the half bridge, variable light output from the LEDs can be realized.

FIG. 3 illustrates HF inverter 20a (FIG. 2) and impedance circuit 30a (FIG. 2) driving an LED array 40b having a LED strings in place of single LEDs connected in "anti-parallel configuration. Alternating current I_{AC} flows through a light emitting diode LED_1, a light emitting diode LED_3 and a light emitting diode LED_5 when alternating current I_{AC} has a positive polarity. Conversely, alternating current I_{AC} flows through a light emitting diode LED_2, a light emitting diode LED_4 and a light emitting diode LED_6 when alternating current I_{AC} has a negative polarity. In alternative embodiments, the LED strings can have differing numbers of LEDs in series as requirements warrant and may be connected in electrically equivalent configurations or in "matrix configuration" as would be known by those skilled in the art.

FIG. 4 illustrates a second embodiment of LED driver 10 (FIG. 1). An impedance circuit 30b includes inductor L_1 coupled in series to a parallel coupling of capacitor C_2, a capacitor C_3 and a capacitor C_4. Impedance circuit 30b directs a flow of alternating current I_{AC} through LED array 40c. An anti-parallel coupling of light emitting diode LED_1 and light emitting diode LED_2 is coupled in series with capacitor C_2. An anti-parallel of coupling light emitting diode LED_3 and light emitting diode LED_4 is coupled in series with capacitor C_3. An anti-parallel coupling of light emitting diode LED_5 and light emitting diode LED_6 is coupled in series with capacitor C_4. Divided portions of alternating current I_{AC} flow through light emitting diode LED_1, light emitting diode LED_3 and light emitting diode LED_5 when alternating current I_{AC} is in a positive polarity. Divided portions of alternating current I_{AC} flow through light emitting diode LED_2, light emitting diode

LED_4 and light emitting diode LED_6 when alternating current I_{AC} is in a negative polarity. The capacitance values of capacitor C_2, capacitor C_3 and capacitor C_4 are identical whereby alternating current I_{AC} is divided equally among the anti-parallel LED couplings.

Capacitor C2, capacitor C3, and capacitor C4 can be low cost and compact surface mounted type capacitors and may be mounted directly to LED array 40c as a subassembly. By driving pairs of LEDs in this manner the driving scheme has the advantage that if one LED fails "open" only one pair of LEDs will go dark as opposed to a whole string as can be the case with other driving schemes. While LED array 40c is shown to consist of three pairs of anti-parallel connected LEDs one skilled in the art can see that anti-parallel connected LED "strings" as illustrated in FIG. 3 could also be connected in the same fashion as could any number of LED pairs/strings/matrixes with a corresponding number of current splitting capacitors. Furthermore, if differing levels of current were desired in different LED pairs/strings/matrixes this can be accomplished by choosing capacitor values of different capacitance inversely proportional to the ratio of current desired.

FIG. 5 illustrates a third embodiment of LED driver 10 (FIG. 1). An impedance circuit 30c includes inductor L_1 coupled in series to a capacitor C_5, which is coupled in series to a parallel coupling of capacitor C_2, capacitor C_3 and capacitor C_4. Impedance circuit 30c directs a flow of alternating current I_{AC} through of LED array 40d. An anti-parallel coupling of light emitting diode LED_1 and light emitting diode LED_2 is coupled in series with capacitor C_2. An anti-parallel of coupling light emitting diode LED_3 and light emitting diode LED_4 is coupled in series with capacitor C_3. An anti-parallel coupling of light emitting diode LED_5 and light emitting diode LED_6 is coupled in series with capacitor C_4. A switch in the form of a transistor T_3 is coupled in parallel to the anti-parallel LED couplings. Those having ordinary skill in the art will appreciate other forms of switches that may be substituted for transistor T_3.

Divided portions of alternating current I_{AC} can flow through light emitting diode LED_1, light emitting diode LED_3 and light emitting diode LED_5 when alternating current I_{AC} is in a positive polarity. Divided portions of alternating current I_{AC} can flow through light emitting diode LED_2, light emitting diode LED_4 and light emitting diode LED_6 when alternating current I_{AC} is in a negative polarity. The capacitance values of capacitor C_2, capacitor C_3 and capacitor C_4 can be proportioned to divide the alternating current IAC into whatever ratios are desired for the individual LED pairs. An operation of transistor T_3 serves to divert alternating current I_{AC} from the anti-parallel LED couplings to thereby turn the LEDs off. Capacitor C_5 is included in this representation to minimize the effective impedance change seen by the half bridge 20a and hence the change in current level I_{AC} when transistor T_3 is switched on and off, but the circuit can also operate with a series resonant capacitance made up of only capacitor C_2, capacitor C_3 and capacitor C_4. It is also possible to substitute LED strings as represented in FIG. 3 or matrix connections of LEDs in place of the LED pairs.

While three LED pairs and capacitors are shown in this representation for demonstration purposes it should be obvious to one skilled in the art that any number of LED pairs, LED strings, and/or LED matrices can be used with suitable capacitors and drive from the half bridge 20a and can be switched with transistor T_3.

FIG. 6 illustrates a fourth embodiment of LED driver 10 (FIG. 1). An impedance circuit 30d includes inductor L_1 coupled in series to a capacitor C_5, which is coupled in series to a parallel coupling of capacitor C_2, capacitor C_3, capacitor C_4 and capacitor C_6. Impedance circuit 30d directs a flow of alternating current I_{AC} through of LED array 40d. An anti-parallel coupling of light emitting diode LED_1 and light emitting diode LED_2 is coupled in series with capacitor C_2. An anti-parallel of coupling light emitting diode LED_3 and light emitting diode LED_4 is coupled in series with capacitor C_3. An anti-parallel coupling of light emitting diode LED_5 and light emitting diode LED_6 is coupled in series with capacitor C_4. Transistor T3 is coupled series to capacitor C_6.

Divided portions of alternating current I_{AC} can flow through light emitting diode LED_1, light emitting diode LED_3 and light emitting diode LED_5 when alternating current I_{AC} is in a positive polarity. Divided portions of alternating current I_{AC} can flow through light emitting diode LED_2, light emitting diode LED_4 and light emitting diode LED_6 when alternating current I_{AC} is in a negative polarity. The capacitance values of capacitor C_2, capacitor C_3 and capacitor C_4 can be proportioned to divide the alternating current IAC into whatever ratios are desired for the individual LED pairs. An operation of transistor T_3 serves to reduce the ampere level of the divided portions of alternating current I_{AC} through the anti-parallel LED couplings by diverting current via capacitor C_6.

It is also possible to substitute LED strings as represented in FIG. 3 or LED matrixes connections in place of the LED pairs.

While three LED pairs and capacitors are shown in this representation for demonstration purposes, those skilled in the art will appreciate that any number of LED pairs, LED strings, or LED matrices can be used with suitable capacitors and drive from the half bridge 20a and that the amplitude of current through these can be switched with transistor T_3 and suitable capacitance C_6.

Those having ordinary skill in the art will further appreciate that multiple levels of illumination can be realized for a given LED array through the use of combinations of switching schemes demonstrated in FIGS. 5 and 6, and through the use of multiple switches and capacitors configured as in FIG 6. If additional capacitors and switches are configured as taught by C_6 and T_3 of FIG. 6, then multiple illumination levels can be accomplished. If a switching transistor is added as taught by transistor T_3 from FIG. 5, an on/off function can be added as well.

In alternative embodiments, further "linear" dimming control could be added to either of the configurations as taught by FIG. 5 and 6 if transistor T_3 in either of them were to be switched in a "pulse width modulated" fashion. If transistor T_3 were switched in such a manner, light output could be controlled

linearly from the maximum and minimum levels determined by "full on" and "full off" states of the transistor T_3 through all light levels in between as a function of the duty cycle of the on time of the transistor T_3.

FIG. 7 illustrates a first embodiment of an illumination system in accordance with the present invention that combines on/off switching features as demonstrated in FIG. 5 with amplitude control features as demonstrated in FIG.6. An automobile rear lighting system is an example of an application for such a requirement. In an automobile rear lighting system, an on/off requirement is used for the turn signal function and two levels of light output are used for the tail light and brake light functions.

HF inverter 20, impedance circuit 30c, and LED array 40d constitutes a turn signaling device whereby an operation of transistor T_3 as previously described herein in connection with FIG. 5 facilitates a flashing emission of light from LED array 40d. HF inverter 20, impedance circuit 30d, and LED array 40d constitutes a brake signaling device whereby an operation of transistor T_3 as previously described herein in connection with FIG. 6 facilitates an alternating bright/dim emission of light from LED array 40d. In this manner, a single half bridge driving stage can be used to control two sets of LEDs independently of each other with varying degrees of illumination.

While FIG. 7 is shown demonstrating one half bridge operating two sets of LED arrays, those having ordinary skill in the art will appreciate that any number of arrays of varying configuration can be connected and operated independently of each other through the control schemes shown the accompanying figures and previously described.

FIG. 8 illustrates a second embodiment of an illumination system in accordance with the present invention that combines on/off switching features as demonstrated in FIG. 5 with amplitude control features as demonstrated in FIG. 6 that can be used as an automobile rear lighting system. An impedance circuit 30e includes inductor L_1 coupled in series to a capacitive array 31a consisting of

capacitor C_2, capacitor C_3, capacitor C_4 and capacitor C_5 as taught by the description of FIG. 5. Inductor L_1 is further coupled in series to a capacitive array 31b consisting of capacitor C_2, capacitor C_3, capacitor C_4, capacitor C_5 and capacitor C_6 as taught by the description of FIG. 6. HF inverter 20, impedance circuit 30e, and LED array 40d constitutes a turn signaling device whereby an operation of transistor T_3 as previously described herein in connection with FIG. 5 facilitates a flashing emission of light from LED array 40d. HF inverter 20, impedance circuit 30e, and LED array 40d constitutes a brake signaling device whereby an operation of transistor T_3 as previously described herein in connection with FIG. 5 facilitates an alternating bright/dim emission of light from LED array 40d. In this embodiment, a single inductor L_1 is used to minimize the size and cost of the controlling circuit.

In the present invention described herein in connection with FIGS. 1-8, those having ordinary skill in the art will appreciate HF inverter 20 and embodiments thereof combine the benefits of small size and high efficiency. Additionally, impedance circuit 30, LED array 40 and embodiments therefore utilize variable frequency, "linear" light output control based on a simple multiple array capability. Furthermore, LED array 40d and variations thereof allow for "step" light output and on/off switching control of multiple LED from a single driver. This type of control can be useful in operating running/stop/turn signals on an automobile or stop/caution/go signals of a traffic light among other uses.

While the embodiments of the present invention disclosed herein are presently considered to be preferred, various changes and modifications can be made without departing from the spirit and scope of the present invention. The scope of the present invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.